Petrographic Analysis of Felsic Tuffs within the Neoarchean Soudan Member of the Ely Greenstone Formation, NE Minnesota

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The Vermilion District of northeastern Minnesota contains one of the classic greenstone belts in the United States, and is composed of a wide variety of greenschist facies metamorphosed Neoarchean volcanic, sedimentary, and intrusive rocks that comprise the southwestern part of the Wawa Abitibi Terrane (Stott et al., 2007). Relative to similar rocks in Canada, the Vermilion District lacks a significant number of geochronological age dates which allow determination of the timespans that it took for various key geological processes to take place. One of the key process timing questions that remains is "How long did it take for the Soudan Member of the Ely Greenstone Formation to form?" The purpose of this UROP research is to identify and characterize felsic tuff horizons that are interbedded with Algoma-type banded iron formations within the Soudan Member of the Ely Greenstone Formation, and determine if they contain significant populations of the mineral zircon that may yield U/Pb age dates. This has been accomplished by detailed field mapping, petrographic studies, scanning electron microscopy (SEM) studies, and ongoing lithogeochemical studies. Several felsic tuff units have been identified; however, to date, no zircon grains have been recognized within these deposits, suggesting that methods other than U/Pb geochronology may have to be employed to yield absolute dates for these strata.

1. Introduction

In recent years, geochronological studies have revolutionized our understanding of the absolute ages of individual rock units, and have been key to identifying the periods of time involved in geological processes during the genesis of Neoarchean (>2.5 billion year old) greenstone belts. These studies involve determining the absolute ages of zircon grains (a mineral with chemical formula $ZrSiO_4$ that can contain trace quantities of uranium (U) and lead (Pb)) from felsic rocks using U/Pb dating techniques (Jackson et al., 2004; Lodge et al., 2013). Thurston et al. (2008) have shown that the ages of iron formations, and the duration of time it took for their deposition, can be ascertained by dating zircons in felsic volcanic rocks that are interlayered with banded iron formation horizons in thick, iron formation dominated rock sequences. The Soudan Member of the Ely Greenstone Formation represents a relatively thick (50-3,000 meters (Hudak and Peterson, 2014)) iron formation dominated rock sequence in the Vermilion District of northeastern Minnesota (Figure 1) that hosted economic iron mineralization at the Soudan Mine.

To date, no efforts have been made to determine the age of this historically and economically significant rock sequence, nor have any efforts been made understand how long it may have taken for this rock sequence to form. Our work seeks to identify felsic tuff horizons in the Soudan Member of the Ely Greenstone Formation that contain populations of zircons that could yield U/Pb age dates.

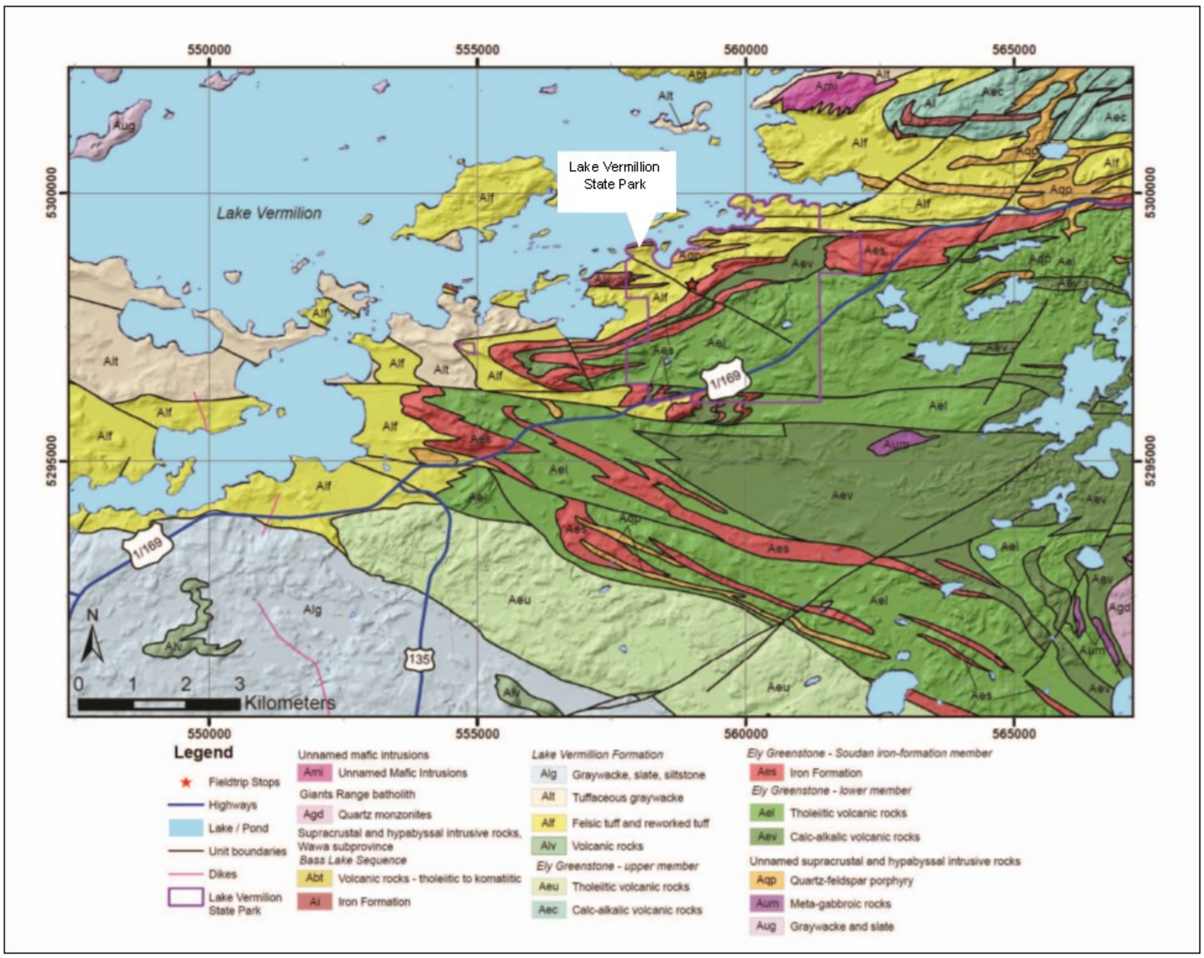

Figure 1: A geological map of the Vermillion District in the vicinity of Lake Vermillion State Park (purple outline). The red star indicates the location of the felsic tuff horizon that was the focus of this study.

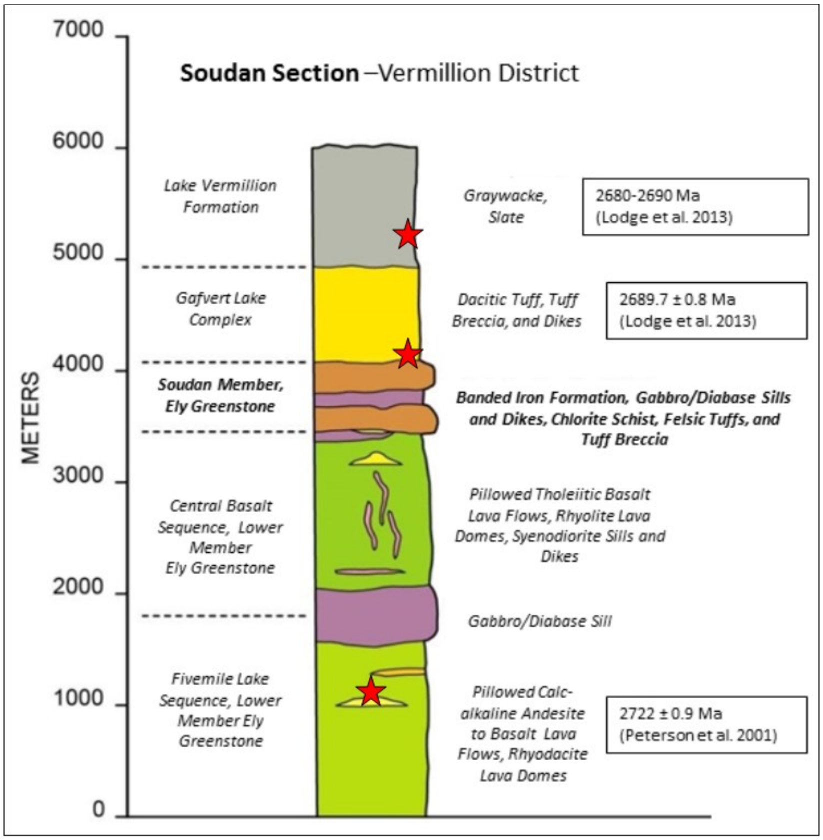

Figure 2. The geologic stratigraphic section in the Vermillion District in the vicinity of Soudan and Lake Vermillion State Park (Hudak et al., 2014). Age dates of strata are indicated and the locations of the dated samples are shown with red stars. As illustrated there are no age dates in the Soudan Member of the Ely Greenstone Formation.

Determining dates for the Soudan Member would have scientific, historical, and educational implications. Dates for rocks stratigraphically below and above the Soudan Member range from 2722 to 2689 Ma (Figure 2; Lodge et al., 2013, 2015; Peterson et al., 2001). Determining the age of the Soudan Member would firmly establish the nature of the contact between the Soudan Member and the overlying Gafvert Lake Sequence, which may be an unconformity (Lodge et al., 2013). Determining this age would have historical significance, as it would allow comparison of ages of ancient Algoma-type iron formations that have been historically mined in North America. Finally, it would have enormous educational implications, as the scientific community, tourists, and school children who have visited Soudan Underground Mine and Lake Vermilion State Park will be closer to getting a definite answer to the questions “How old are these rocks?” and potentially, “How long did it take them to form?”

2. Methods

Our investigation of the Soudan Member has utilized a variety of scientific methods, including detailed field mapping and sampling, petrographic studies, scanning electron microscopy (SEM) studies, and ongoing lithogeochemical studies. Field mapping and sampling took place in October, 2014, when several outcrops comprising Soudan Member Algoma type iron formation were evaluated for potential felsic tuff horizons. Outcrops for field investigation were selected based on previous detailed (1:5,000 scale) mapping performed in Lake Vermilion State Park (Radakovich et al., 2010; Heim et al., 2011). Field descriptions were made of felsic tuff horizons (Figure 3) that were identified, and these tuff horizons were subsequently sampled. All sample locations were documented with photographs, and the locations for each of the samples were identified using a hand-held geographic positioning system (GPS). Both standard (glass cover slide) and polished thin sections were made from the samples. Polarized light petrography was followed up by detailed physical and mineralogical characterization of the samples using the energy dispersive x-ray detector (EDS) and the electron backscatter diffraction system (EBSD) employed by the scanning electron microscope (SEM) at UMD's Research Instrumentation Laboratory. Ongoing major- and trace-element lithogeochemical analysis is currently being performed by geoscientists at the University of Wisconsin Eau Claire.

Figure 3. Felsic tuff horizon that occurs approximately 25 meters from the stratigraphic top of the Soudan Member of the Ely Greenstone Formation. This felsic unit is interbedded with Algoma-type banded iron formation and chert deposits which comprise the major lithologies within the Soudan Member. Note the difference in appearance between chert deposits (upper part of photo) and the felsic tuff unit (lower part of photo). This felsic tuff unit was the focus of our studies.

3. Results

Detailed mapping identified several felsic tuff horizons within the uppermost 25 meters of the Soudan Member of the Ely Greenstone Formation in the east-central part of Lake Vermilion State Park (Figure 1). Most of these tuff horizons were too thin (1cm-5cm in thickness) to be adequately sampled. However, a single, light gray, 30-50cm thick, laminated to thinly-bedded, possibly resedimented felsic tuff horizon interlayered with laminated to very thinly-bedded magnetite-chert Algoma-type banded iron formation that occurred in this area was easily sampled (Figure 3). This felsic tuff horizon was the focus of our study.

Petrographic studies indicated that the felsic tuff is sparsely quartz-phyric, and comprises a matrix of fine-grained, recrystallized polygonal quartz with up to 1%, up to 1mm in diameter subhedral, recrystallized quartz phenocrysts (Figure 4). Hydrothermal alteration of the tuffs varies from moderate to intense (up to 80% alteration minerals), with the greenschist-facies metamorphosed synvolcanic hydrothermal alteration assemblage now composed of variable amounts of subhedral polygonal recrystallized quartz (25-90%), subhedral to radial acicular grunerite (10%-70%), subhedral platy chlorite (<1-10%), subhederal to euhedral magnetite (2-7%), anhedral to subhedral rhombic iron carbonate (siderite, ankerite; <1-2%), patches to veins of stilpnomelane (<1-2%), and various subhedral equant epidote-group minerals (pistacite, clinozoisite/zoisite; <1-3%). Examples of the textures and minerals identified petrographically are illustrated in Figure 5. Due to the extremely fine-grained texture of the tuff, and the locally pervasive hydrothermal alteration within the tuff, searching for zircons using standard petrographic analysis proved difficult.

Subsequent mineralogical and textural characterization of the tuffs was carried out via EDS and EBSD analysis using scanning electron microscopy (Figure 6). In addition to the aforementioned minerals, trace amounts of allanite, monazite, and apatite were identified. To date, no zircon grains have been identified by means of standard petrography or SEM analysis. Whole rock major- and trace element analyses of the tuffs is ongoing with results anticipated later this spring.

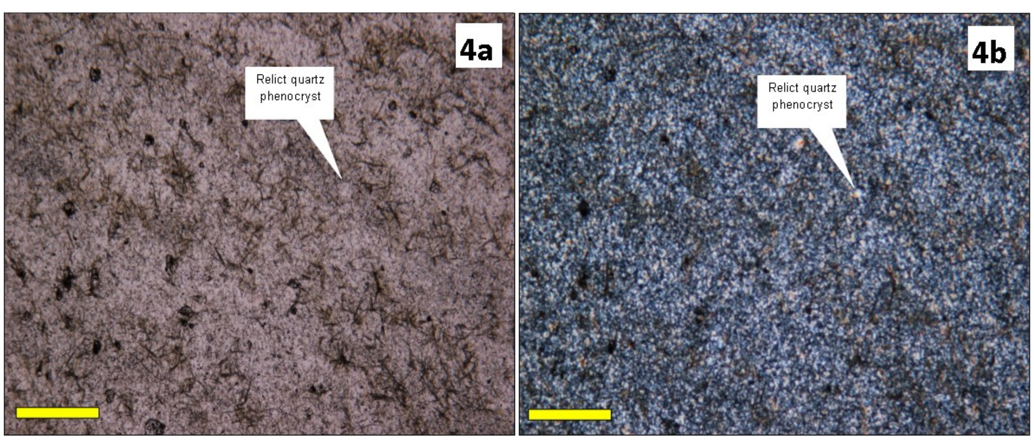

Figure 4: Photomicrographs in both plane polarized light (4a) and cross polarized light (4b) of sample EE-14-01-1. Note the presence of trace amounts of <1 mm relict quartz phenocrysts in the deposits which indicates they are felsic tuff. Note that the tuffs are variably hydrothermally altered and contain a quartz-rich matrix with grunerite amphibole and epidote group minerals.

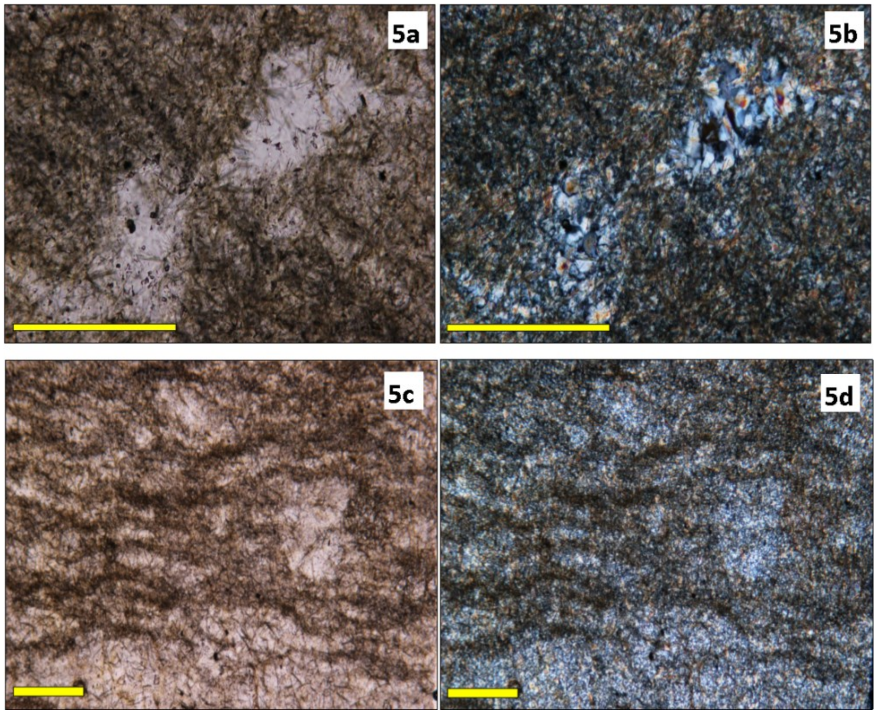

Figure 5. Photomicrographs taken from sample EE-14-01A in both plane polarized light (left) and cross polarized light (right). In Figures 5a and 5b one can see the local intensely altered tuff which comprises a mineral assemblage of quartz, grunerite, and minor chlorite that is cut by a quartz vein. Figures 5c and 5d illustrate alteration bands composed of acicular to locally radial grunerite. Scale bars in each photo are 1 mm.

4. Discussion

The first goal of this research has been to document the presence of felsic tuff horizons within the Algoma-type banded iron formation dominated Soudan Member of the Ely Greenstone Formation. We have accomplished this goal by documenting the presence of several potential felsic tuff horizons within the uppermost 25 meters of the Soudan Member in the central part of Lake Vermilion State Park.

Our second goal has been to characterize the textures and mineralogy of potential felsic tuff horizons identified during the field phase of our research by means of standard petrographic studies and subsequent scanning electron microscopy, with an emphasis on identifying the presence of the mineral zircon that may be able to be analyzed by means of U/Pb geochronological studies and yield absolute age dates for the felsic tuffs. Based on our standard petrographic analyses, textures within the potential felsic tuff units are consistent with those that characterize felsic tuffs. The most important observation is the presence of relict quartz phenocrysts within the rocks that distinguishes them as felsic tuffs rather than another type of fine-grained quartz-rich rock such as chert. Hydrothermal alteration within the tuffs was considerably more prevalent than initially anticipated based on our field observations, and the abundance of hydrothermal alteration phases and textures made identification of trace, small mineral phases such as zircon grains difficult. Subsequent studies of the fine-grained, altered tuffs by means of scanning electron microscopy yielded important mineralogical information, particularly for extremely small, trace minerals phases that occur within the tuffs (for example, the presence of allanite and monazite). As well, scanning electron microscope studies were essential to identifying mineralogical phases present in the rocks studied, in particular, carbonate (siderite, ankerite) and amphibole mineral (grunerite) species. Scanning electron microscope studies also confirmed the absence of the mineral zircon, which was not identified during our standard petrographic studies of samples of the felsic tuff. We anticipate that the trace element lithogeochemical analysis of the felsic tuff that is currently ongoing will indicate low concentrations of the element zirconium in our samples.

The lack of zircons in the felsic tuff unit evaluated in our study is not unique. In some cases, petrological processes in felsic volcanic rocks inhibit the growth of the mineral zircon. As well, given the extremely fine-grained nature of the felsic tuffs, the felsic tuffs that were the focus of our study may have been resedimented prior to lithification, and may have been deposited a significant distance from their original volcanic eruptive center. Given the high specific gravity of zircon (~4.68 g/cm3) relative to other primary phases in the tuff (such as felsic ash with an anticipated specific gravity of less than 2.8 g/cm3), zircons may have been deposited closer to the volcanic center as a result of gravitational processes.

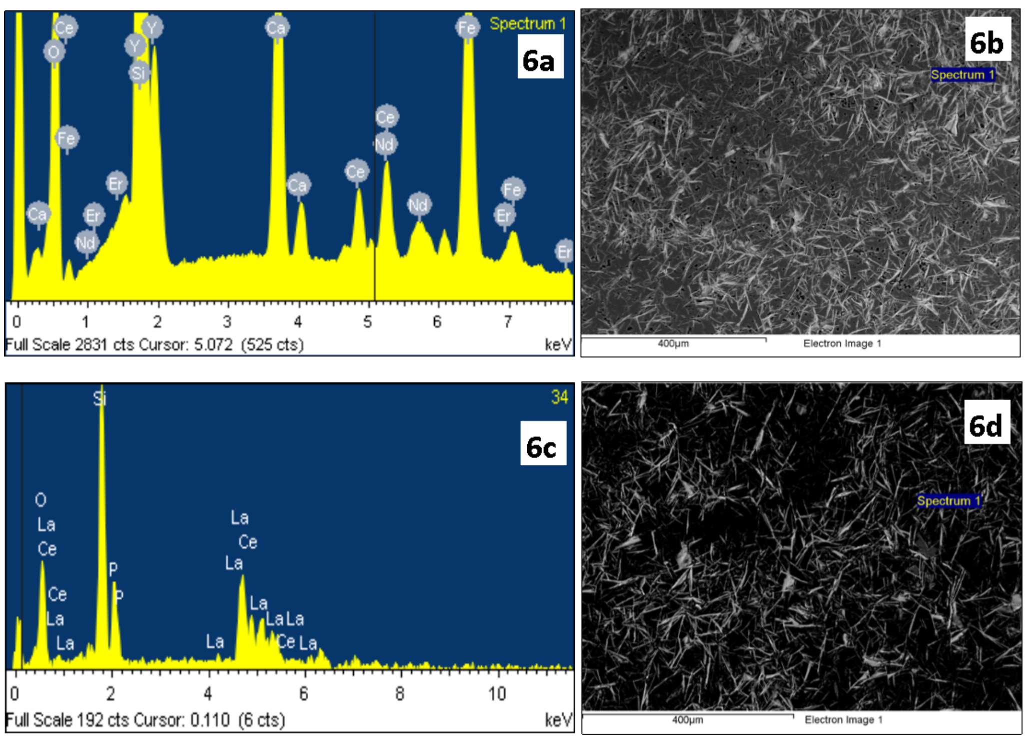

Figure 6. Figure 6a displays an element map of the mineral allanite, a cerium bearing epidote group mineral which occurs in sample EE-14-01-1. Figure 6b is an electron backscatter image of sample EE-14-01-1 where the allanite analysis took place. Figure 6c displays an element map of the mineral monazite, a phosphate mineral that contains rare-earth elements in sample EE-14-01A-2. Note that the large silica spike is the result of spectra being gathered from the quartz-rich matrix. Figure 6d is an electron backscatter image of sample EE-14-01A-2 where the monazite analysis took place.

5. Summary

The Soudan Member of the Ely Greenstone Formation has historically been a stratigraphic horizon of economic, historical and scientific interest. Recent studies have used geochronological methods to find the exact age dates and duration of formation for similar iron-formation dominated stratigraphic sequences within greenstone belts (Thurston et al. 2008), suggesting that telsic tuff deposits in the Soudan member could be dated in a similar way. This method includes the dating of zircon grains that may contain trace quantities of uranium (U) and lead (Pb). No attempts to date the Soudan Member have been completed to date, and such dates would have scientific, historical, and educational implications. These dates would establish the nature of the potential unconformity that lies between the Soudan Member and the overlying Gafvert Lake Sequence (Lodge et al., 2013) as well as provide insight about other similar Algoma-type iron formations that have had significant economic value in North America throughout history. Multiple scientific methods were used to identify and characterize felsic tuffs interlayered with laminated to very thinly-bedded magnetite-chert banded iron. Standard petrographic microscopy and identification of zircons was complicated by the extremely fine-grain size as well as by the hydrothermal alteration and green-schist metamorphism that often overprinted primary structures. Through careful textural analysis, the presence of ghosted relict quartz crystals indicates that these are felsic tuff units and not the fundamentally different cherty horizons that are common within banded iron. This textural distinction is key for determining whether or not there is any future geochronological dating potential within the Soudan Member. Additional EDS and EBSD analysis was conducted using scanning electron microscopy to further confine the mineralogy of the samples and seek out zircons in a more systematic manner. Further geochemical analysis is ongoing, which will allow for a more in depth investigation of major and trace elements. The inability to identify zircon grains during our study suggests that other methods of geochronology may have to be considered in order to date these rocks.

6. Conclusion

Although no zircon grains were identified, we were able to identify several felsic tuff horizons within the Soudan Member of the Ely Greenstone Formation by detailed field mapping, petrographic studies, scanning electron microscopy (SEM) studies, and presumably, lithogeochemical studies. The extremely fine-grained nature and pervasive hydrothermal alteration within the felsic tuff made identifying zircons particularly difficult by standard petrographic methods. Differences regarding the specific gravity of phases within the tuff may have resulted in the differential deposition after eruption. Lack of this key mineral phase in the felsic tuff horizon that was the focus of our research indicates that U/Pb geochronological age dates are not likely to be successful for dating this felsic tuff horizon in the method used by Thurston et al. 2008. Future research regarding the Soudan Member may include more thorough sampling as well as considerations for other methods of geochronology that may allow for more insight regarding the absolute age of the Soudan Member of the Ely Greenstone Formation, as well as how long it may have taken for the Soudan Member to be deposited.

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